

Year 1 Progress Report for NASA AISR Grant

NNG04GP83G: A Numerical Simulation Tool for Planetary Subsurface Radar

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This document reports the progress of the AISR funded research on development of a simulation tool for the complete orbital planetary ground penetrating radar (GPR) problem. The primary personnel supported by this project are the PI, Prof. Steven Cummer of Duke University, and the PhD student Yanbin Xu of Duke University. As shown in the report, we have made substantial progress towards the stated goals in the proposal. An initial version of the complete tool has been developed on the Matlab platform and has been distributed to targeted users in the science community for feedback. We presented the initial version of our simulation tool at the workshop on Radar Investigations of Planetary and Terrestrial Environments held at Houston in February 2005 in order to advertise the work and solicit input from the scientific community about what would be most useful in the tool. To demonstrate the science value of the tool, we applied our model towards answering the question of whether key Martian polar subsurface targets such as basal lakes are detectable using orbital GPR. Scientists including those from the MARSIS team expressed significant interest in using our model. In the following of this report, we will first briefly state our research objectives, and then list the progress we have made compared to the goals listed in the proposal.

Summary of Proposed Research

The primary goal of the proposed research is to develop and deliver a versatile and general simulation tool for the complete planetary ground penetrating radar (GPR) problem. GPR is a relatively mature technology for a variety of planetary subsurface remote sensing applications. Correct interpretation of the planetary GPR data is hence the key to studying the target ground parameters of the unknown planetary bodies. As the investigators know, there are currently no simulation tools available in the planetary community that can include essentially all of the important orbital GPR effects, such as the 2D subsurface features and the ionosphere, and there is a compelling need for meaningful quantitative simulation of the planetary GPR problem, which can help bound the data interpretation and instrument design.

We proposed to develop a versatile computer code for the numerical simulation of the planetary GPR problem from source to scattering to reception. The model will be 2.5D, with 3D fields and the capability for treating 2D subsurface and surface inhomogeneities. The code will be designed to be as general as possible to handle arbitrary planetary ionospheres, arbitrary surface roughness, and arbitrary subsurface electrical parameters and structure. Our approach of basing the simulation on time

domain methods, in which the entire computational volume is discretized, handles this generality almost automatically. The computational volume will be split into two pieces, one treating the near surface and subsurface fields and the other treating the ionospheric propagation. By accounting for essentially all of the important GPR effects that can be difficult to compute analytically, the model enables accurate numerical experimentation with realistic instrumental and environmental parameters.

Proposed Goals for Year 1 & 2

Here we list the goals for the first two years as stated in the proposal since some parts of the work are slightly ahead of schedule. They are:

Year 1:

- Complete surface/subsurface FDTD simulation component and combine with WKB-approximation ionosphere component.
- Present initial results at a relevant meeting to solicit from community.

Year 2:

- Develop surface/subsurface PSTD simulation component and compare efficiency to FDTD component.
- Develop ionospheric FDTD simulation component and method to determine whether to use FDTD or WKB for the ionospheric calculation.
- Begin code validation by comparing output from each component separately with simplified analytical calculations.

Current Research Accomplishments

- Subsurface scattering component of the model with the FDTD method was completed. It was validated with a comparison to analytical calculations for simple layered geometries.
- Subsurface scattering component of the model with the PSTD method was studied. We found that the PSTD method was not so stable as FDTD the method, and it was good only for scatters with regular shape, such as a square object. So the FDTD method is more general than PSTD and hence we choose FDTD method to calculate subsurface scattering.
- Atmospheric and ionospheric propagation component of the model with WKB-approximation was completed. The important ionospheric effects were included in the wavenumber k in the near- far- field transformation.
- The FDTD scattering component and the WKB-approximation propagation component were combined to calculate the reflected signals received by orbital GPR. We validate the model by calculating the signals received by the orbital GPR 250 km (a usual satellite altitude) above a perfect electrical conductor (PEC) in free space.
- Modeled rough surface interfaces and realistic ionospheric profiles were included in the simulation to determine their impact on GPR operation.
- Surface scattering coming from the off-nadir illuminated area, known as clutter, was added to the model since clutter may mask the subsurface target reflections due to the longer travel time for off-nadir reflections.

- Some signal processing techniques such as chirp signals were included in the simulator to make the simulated radar echoes more realistic. For example, MARSIS transmits a 250 μ s chirped pulse with 1 MHz bandwidth.
- An automatic version of the simulator with friendly user interface was developed using MATLAB as the initial platform for rapid development.
- We applied our model towards answering the question of whether key Martian polar subsurface targets such as basal lakes at 2.5 km depth are detectable by MARSIS.
- The observability of expected water-associated subsurface features from orbiting platforms, including detrimental ionospheric effects, was investigated.
- The Matlab-platform code has been distributed to Dr. William Farrell of NASA GSFC for feedback on the current capabilities of the code. Dr. Farrell is a close collaborator and a participating scientist on the MARSIS GPR instrument.

Currently we are validating our model with published GPR data. We have established connections with scientists from the Lunar and Planetary Institute, a NASA funded institute, who will send us samples of real GPR data. And most important of all, MARSIS has begun to collect data on Mars recently and we can try our simulator on interpreting the MARSIS data in the near future.

Publications and Presentations

Xu, Y, S. A. Cummer, and W. M. Farrell, Application of an orbital GPR model to detecting Martian polar subsurface features, submitted to *JGR-Planets Special Section on Radar Investigations of Planetary and Terrestrial Environments*.

Y. Xu, S. A. Cummer, and W. M. Farrell, Application of an orbital GPR model to detecting Martian polar subsurface features, talk presented at Radar Investigations of Planetary and Terrestrial Environments Workshop, Lunar and Planetary Institute, Houston, TX, February 2005.

Example Simulation Results

We will present some example simulation results in answering the question whether basal lakes at 2.5 km depth under the Mars north polar cap are detectable. Basal lakes are defined as water reservoirs formed at the underside of an ice mass and represent a key target for MARSIS during its northern low-perigee polar overpasses. Figure 1 is an MGS/MOC image of Mars north polar layers with 2.5 km depth. The brighter top region is suggestive of a set of ice/snow layers with a relatively low concentration of dust while the darker region has a large amount of sand. Figure 2 is the A-scan simulation results that compare the signal returns between propagation through free space and through the ionosphere. The MARSIS is at 250 km altitude and nighttime ionosphere profile is used. The two-way ionosphere effect on the signal is basically 10 dB attenuation and 5 μ s time delay. Figure 3 is the B-scan simulation results. Some of the colors are saturated to clarify basal lake reflections. Using our simulator, we find that a basal lake located about 2.5 km below the surface is near the limit of detectability for MARSIS. And Figure 1 is also a good example that the FDTD

method can handle the problem easily while PSTD cannot due to the irregular inhomogeneities of the subsurface.

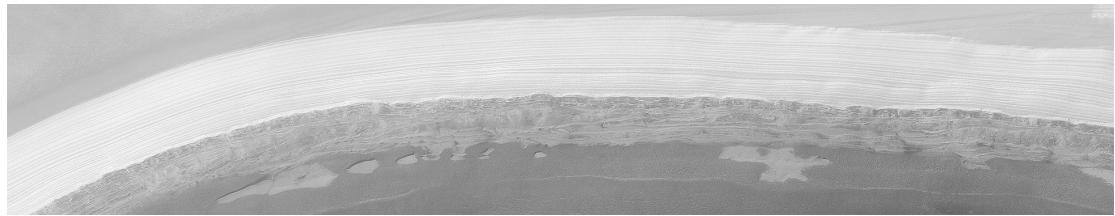


Figure 1. MGS/MOC image of Mars north polar layers
[\(http://photojournal.jpl.nasa.gov/\)](http://photojournal.jpl.nasa.gov/).

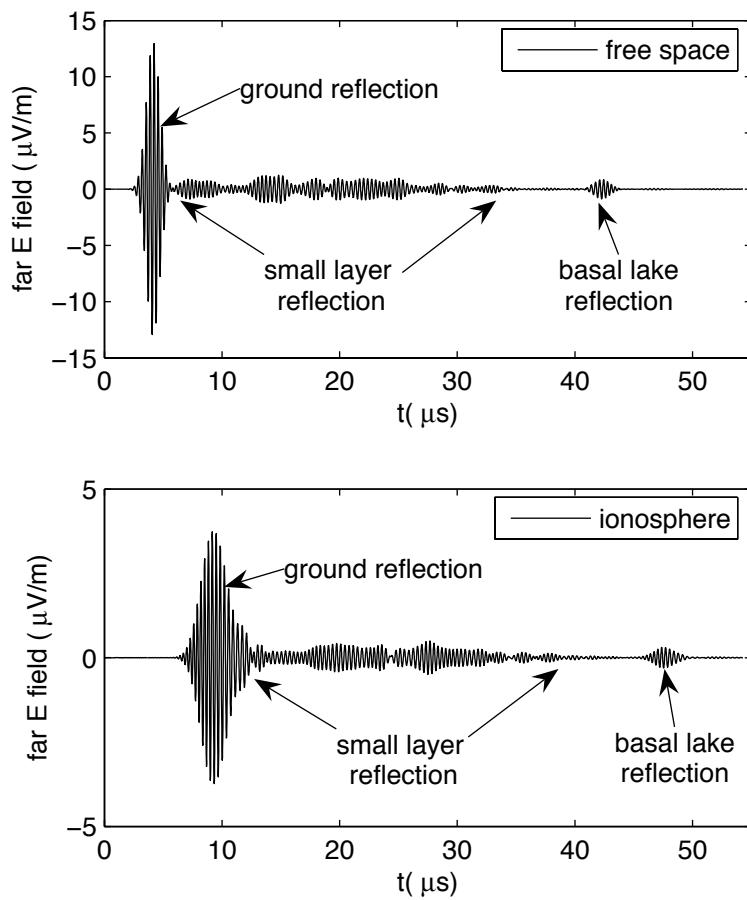


Figure 2. Simulation results for single pulse A-scan.

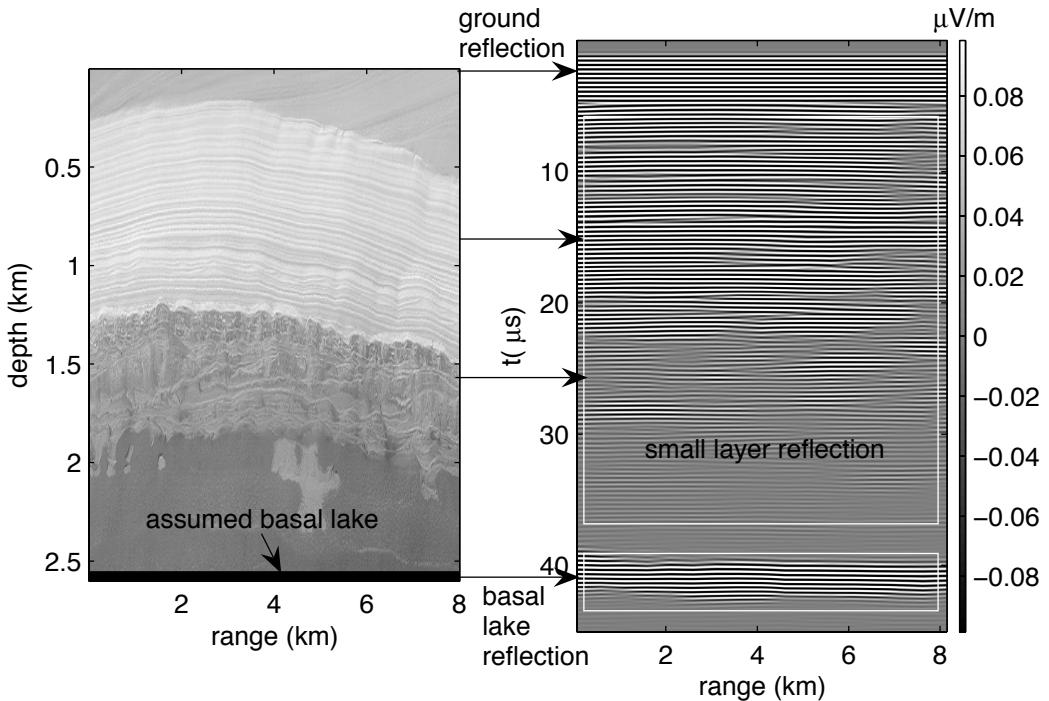


Figure 3. Simulation results for single pulse B-scan over the Mars north polar cap.

Tasks to be carried out in Year 2

The following tasks will be carried out in the following year:

- Validate model with published GPR data and analysis.
- Develop ionospheric FDTD simulation component and method to determine whether to use FDTD or WKB for the ionospheric calculation.
- Distribute the model more widely to groups involved in the design of and interpretation of data from planetary GPR instrumentation.
- Improve code capabilities based on community feedback
- Begin development of cross-platform code